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FOREIGN TECHNOLOGY DIVISION



THE WAY TO SPACE

by

Yiyun Zhou and Ruicheng Li



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THE WAY TO SPACE

By: Yiyun Zhou and Ruicheng Li

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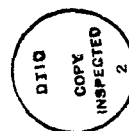
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PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

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THE WAY TO SPACE

Krushevko was a well known Soviet expert on liquid propellant rockets. During his sixty years of research, he developed many kinds of rocket engines. He was indeed a key person in the Soviet Union's studies of missiles and aeronautics. This article is translated from part of his autobiography, which describes the development of rocket propulsion in the Soviet Union.

In 1922 I read about Zirchovskiy in "Inter-Planetary Travelling" written by Bellerman. Unfortunately, many of Zirchovskiy's works could not be obtained from the libraries at that time. So I decided to consult with him directly. In September, 1923, I wrote him a letter, describing my interest and ideas about space travelling and asking for his publications. In early October, I received his reply and later in the same month, he sent me his books twice.

Zirchovskiy had already solved the problems of space travelling theoretically. I had a strong desire to implement these theories. Hence the development of rocket engines became my lifelong aim.

I accumulated some necessary knowledge and was involved in some design works in high school, and later in college. Nevertheless, it was not until 1924 that I gained some experience in experimental works at the Gas Dynamics Laboratory in Leningrad. The first three liquid propellant rockets developed by the Soviet Union, also called "jet propelled flight vehicles", employed the OPM-52 engine, which had a thrust of 300 kg and could launch a vehicle to an altitude of 2 km and 4 km. These rockets were manufactured in the machine shop in Mochnitah and the Gas Dynamics Laboratory in Peterobaprovsk. The first two rockets, RLA-1 and RLA-2 did not have control systems, while the third could be controlled. It had an instrument cabin containing two gyroscopes

adopted from torpedos used by the navy, and had a pair of rudders on the fins. Control was done by a pneumatic servo-mechanism and some mechanical link-ages.

In the fall of 1933, the Jet Propulsion Research Institute was officially established. Both the Gas Dynamics Laboratory and the National Jet Engine Research Institute were merged with this new institute. Since then, the development of rocket engines and the development of rockets were conducted separately. This was because each field had become quite complicated and specialized. When I was asked to select the field of specialization, I picked the starting point of rocket technology - the development of rocket engines. I think the basis of space travelling is dynamic engineering. If the fundamental problems were not solved, space flight is nothing but a dream.

CHARACTERISTICS OF THE LIQUID PROPELLENT ROCKETS

Unlike all other kinds of engines (including aircraft engines), the flow process in a liquid propellant rocket engine is extremely vigorous. Within a combustion chamber of only a few liters, hundreds or even thousands of kilograms of fuel are burned in each second. Under such combustion conditions, the combustion efficiency approaches unity, the chamber pressure reaches as high as 200 to 300 atmospheres, the steady state absolute temperature can be as high as 4400 degrees, and the jet velocity reaches as high as 4500 meters per second. Consequently, the heat flow rate across the walls of the combustion chamber and the nozzle is tremendously high. All these factors may cause instability in the operation of the engine. Even self-vibration in a wide frequency range could produce tremendous vibrational overloads. Hence methods to prevent the occurrences of such phenomena must be investigated. The corrosive, poisonous, cryogenic and multi-phase properties of the propellents also complicate the operation of the engine. All these problems are less serious in other kinds of engines. Furthermore, the super-light rocket engines operating under such vigorous conditions must demonstrate a high

structural reliability, otherwise who is willing to install them on the rockets of manned space vehicles?

During the process of liquid propellant rocket development, many complex technical problems must be overcome. The most essential one is reliability, that is, the possibility of complete combustion of a large quantity of propellant in a combustion chamber of very small volume and the stability of the process. Secondly, the fluctuation of chamber pressure must be eliminated to avoid possible accidents. Thirdly, effective cooling of the chamber wall and the nozzle wall and uniform flow of the combustion product in the nozzle must be ensured to avoid excessive stress and fatigue.

Compared with modern aircraft jet engines, the liquid propellant rocket engines are simple in structure. However, extremely complex problems lie beneath the simple appearance. Some of them have been mentioned above. Here I would like to point out that the problems in modern liquid propellant rocket engines are so complex and difficult that they are impossible to solve without the aid of high speed electronic computers. A system of hundreds of linear and non-linear equations is sometimes required to describe the process in the engine.

So far the process in the liquid propellant rocket engine has not been investigated completely. Present theories are still unable to solve all the problems or to predict accurately the stability of the engine, especially in the area of combustion with high-frequency vibration. Hence an experimental investigation of the process in the engine is still indispensable for the development of new rocket engines. Sophisticated laboratories and test facilities are necessities.

PRINCIPAL WAYS OF IMPROVEMENT

In the forties, some industrial nations succeeded in developing various types of liquid propellant rocket engines. However, the combustion chamber structures of these engines designed in

the Soviet Union or any other countries had no major breakthrough in the improvement of engine thrust, especially the specific thrust which is a principal indicator of degree of perfection and effectiveness of the engine.

At the close of the forties, experience accumulated by the designers indicated that practical improvements in the performance of the engine could only be reached by raising the pressure and the temperature in the combustion chamber. This would result in a higher rate of heat flow across the wall of the chamber. To prevent the chamber wall from overheating, it had to be made as thin as possible. But calculations showed that a thinner wall could not withstand higher pressures. In order to get rid of such a dilemma, completely new structural designs for the combustion chamber had to be developed.

Exploration in this direction was eventually fruitful. Structural forms of those shown in Figure 1 were employed. The additional rib wall (hot wall) is welded on the cold outer wall along the tips of the ribs. In this way, the coolant flowing between the ribs prevents the hot wall from overheating effectively while the ribs still withstand high pressures of hundreds of atmospheres due to the small cross-sectional area of the passages.

When making the inner wall of the combustion chamber, we used thin, fast-conducting bronze materials for the hottest portions and alloys of steel, titanium and other metals for the other portions. The inner and outer walls were welded together. The chamber pressure is transmitted to the cold outer wall of steel through the ribs.

The ability to operate at higher pressures and temperatures of the new combustion chambers creates the possibility of utilizing high heating value propellents.

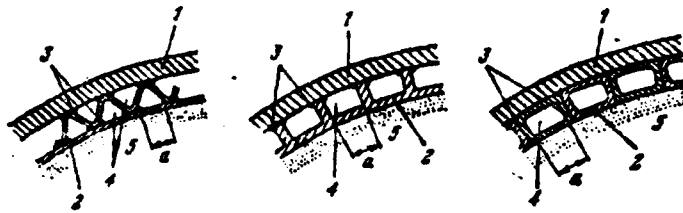


Figure 1. Types of combustion chamber wall structure of rocket engines: Wave form (left); Rib form (middle); Pipe form (right); 1.- outer wall of the combustion chamber; 2 - cooled inner wall; 3 - welded; 4 - passage for coolant; 5 - combusting gas.

During the following decades, the liquid propellant rocket engines continued to improve. For instance, the RD-107 engine for the first stage of the rocket "Orient", and the RD-108 engine for the second stage (Figure 2) were very successfully designed. They are still reliable for launching manned space craft and unmanned exploring vehicles.

The RD-107 and RD-108 engines and their improved models have been utilized successfully for launching many earth satellites, lunar satellites, probes for the planets Venus and Mars, and also manned space craft such as the "Orient", the "Ascension" and the "League", etc. The RD-119 engine (Figure 3) and the RD-214 engine used on the rocket "Cosmos" are still under continuous usage.

In order to improve the relative thrust of the engine, the stagnation pressure of the combustion chamber has to be increased. However, this is restrained by the energy dissipated through the driving turbine pumps.

For those readers who are not experts in our field, I must point out the following facts. The function of the turbine pumps is to deliver the propellant into the combustion chamber. They

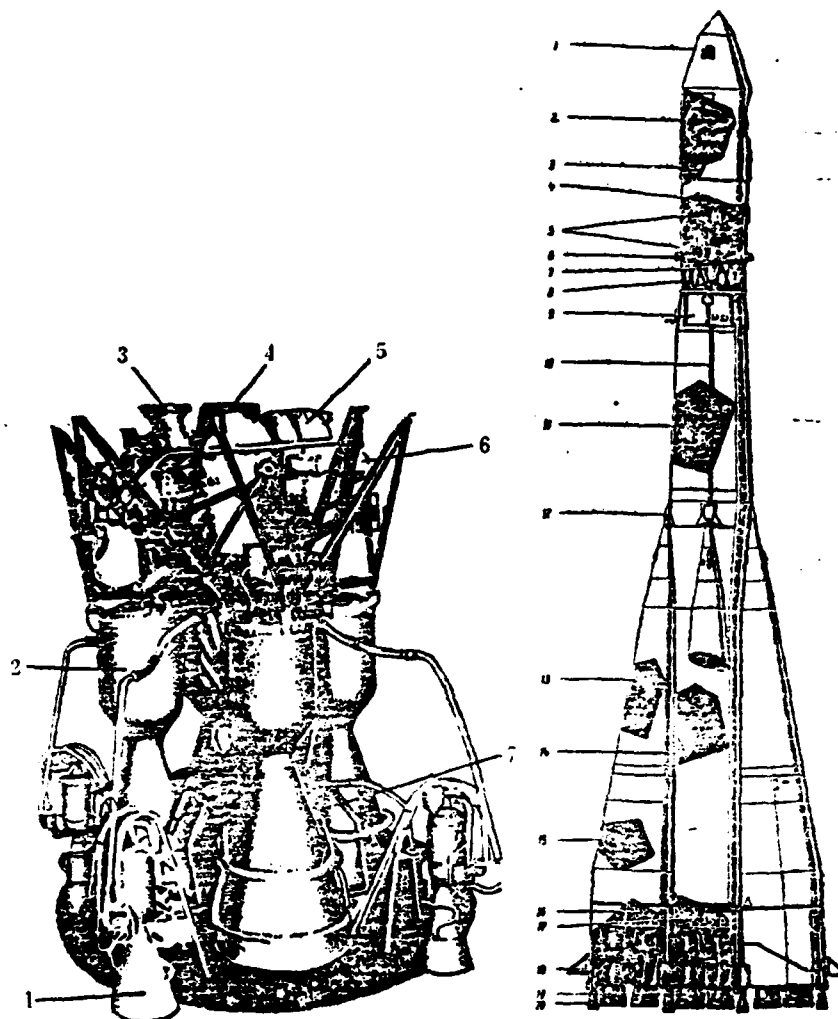


Figure 2. The rocket "Orient" (right) and its second stage RD-108 engine (left). Engine Structure: 1- boosters; 2 - main combustion chambers; 3- inlet to fuel pumps; 4 - inlet to oxidizer pumps; 5 - heat exchanger; 6- gas generator; 7 - fuel pipes.

are composed of pumps and gas turbines which are driven by the gas from the gas generators. To keep the turbine pumps operating, some of the gas must lose some energy, resulting in a reduction in specific thrust. If the pressure in the combustion chambers developed by us does not exceed 75 to 79 atmospheres, the loss in specific thrust is approximately 0.8 - 1.7%, which can still be tolerated. However, if the chamber pressure is to be multiplied, the loss will be increased to an intolerable degree.

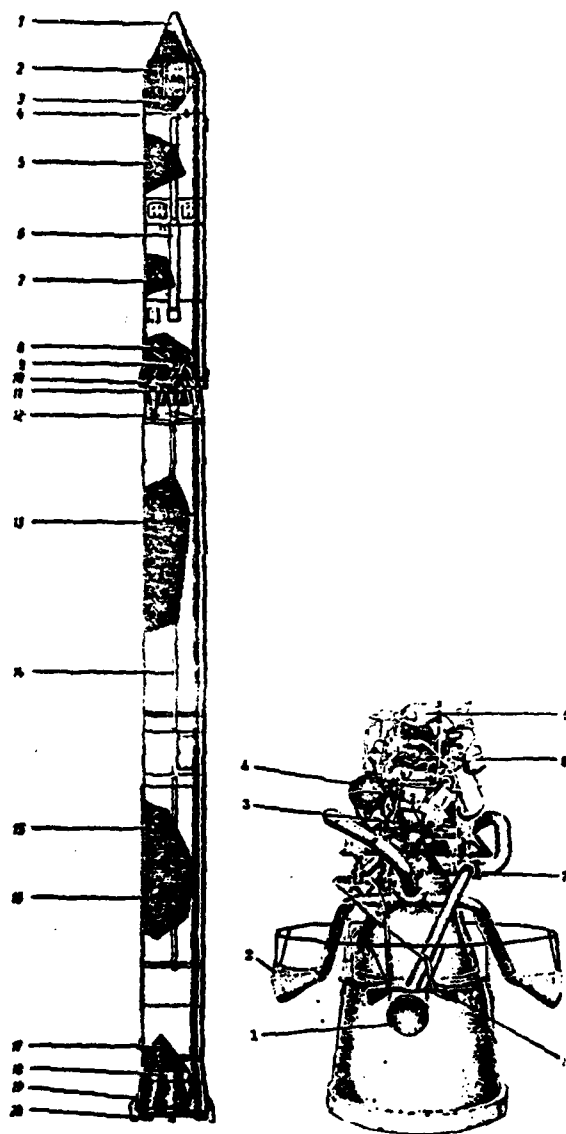


Figure 3. The Rocket "Cosmos" (left) and its Second Stage Engine Structure (right): 1,2- pitching and yawing boosters; 3 - combustion chamber; 4 - compressed air; 5- turbine pump; 6 - gas generator; 7- gas distributor; 8- rotation boosters.

Fortunately, the solution to this issue was found. In the modern design for liquid propellant rocket engines, the exhaust gas from the turbine pumps is allowed to return to the combustion chamber and is allowed to burn with the liquid propellant of richer oxidizer. In this way, the loss through the turbine pumps could be practically reduced to a negligible degree.

If the chamber pressure can be maintained at several hundred atmospheres, engines of very small dimensions but very high thrust can be produced. Following this design concept, we developed the RD-253 engine for the rocket "Proton".

Some of the ways of improving modern liquid propellant rocket engines have been summarized above. Other general improvements involve stabilizing the combustion process, increasing the payload, and utilizing other forms of more effective energy.

BEARING THE BURDEN OF AERONAUTICS AND ASTRONAUTICS

Generally speaking, the emergency and landing systems of space craft employ solid propellant rocket engines and their orbital navigation systems employ electric rocket engines. Compared to the liquid propellant rocket engines, their missions are auxiliary because they rely mainly on the liquid propellant rocket engine to launch the space craft to outer space and to propel it during flight. In other words, the liquid propellant rocket engine bears the burden of astronautics.

The birth and the development of nuclear rockets and electric rockets still cannot replace the liquid propellant rocket engine's launching and re-entry roles. This means that liquid propellant rocket engines are indispensable when a large quantity of energy is required. Moreover, they do not cause radioactive pollution. Unless energy sources with capacities higher than the chemical fuels and "cleaner" than the nuclear fuels are discovered, the liquid propellant rocket engine can

never be replaced.

The perfection of the engine structure is more meaningful in rocketry than in other aviation technologies. Nowadays, a launching weight of 25 to 50 kg is required to deliver a payload of 1 kg to orbit. If the structural design of the rocket engine is not perfect enough, then a considerable amount of its thrust must be spent on the launching and acceleration of its own weight. Hence the effective payload - satellites, space craft launched by the rocket to space depends greatly upon the degree of perfection of the engine.

Among other aviation technologies, the engines for vertical takeoff and landing aircraft are most demanding. According to reports from foreign sources, turbine jet engines satisfying the vertical take-off requirement for such aircraft have already been developed. Their weight-thrust ratio (the ratio of the structural weight of the engine to the thrust produced) reaches 60 to 70 grams for each kilogram of thrust.

This index for the rocket engines is also an order of magnitude higher. The high thrust liquid propellant rocket engines produced in the Soviet Union have reached a weight-thrust ratio of 7 to 10 grams for each kilogram of thrust, that is, the weight of the engine is only 100th to 150th of the thrust it produces. Such a fulfillment can only be accomplished on the basis of high reliability of the combustion process, high index in the performance and application of new structures and new, light materials of high strength.

(Edited by Zhou, Yiyun and Li, Ruicheng)

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